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Kentucky Water Resources Annual Symposium

2018 Kentucky Water Resources Annual Symposium

Mar 19th, 10:30 AM

Session 1A: Groundwater and Karst

Kentucky Water Resources Research Institute, University of Kentucky

SESSION 1A: GROUNDWATER AND KARST

ANALYSIS OF THE AMBIENT GROUNDWATER QUALITY MONITORING NETWORK DATA

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The Kentucky Interagency Groundwater Monitoring Network (or Network) was established to meet three major goals relative to groundwater resources: 1) provide baseline data; 2) characterize the resource; and 3) disseminate the information collected. Previous studies have had a relatively narrow scope and focused on either characterizing the current condition of groundwater in specific river basins or regions of Kentucky or evaluating a single parameter statewide. This report represents the initial examination of statewide trends in groundwater quality based on data collected through the Network over the course of 20 years. In general, data indicate that groundwater quality in Kentucky continues to be suitable for many purposes and that trends are observed for several analytes. The analyte groups and specific analytes evaluated for this study are summarized in the table below.

Analyte groups and specific analytes in this study:

Analyte Group	Summary Comments	Included in Analysis
Bulk Parameters	Basic chemistry and general water quality	pH, Field Conductivity, Temperature, Total Hardness (calculated)
Nutrients	Naturally occurring and NPS influence	NO_3, NO_2, PO_4, TKN, Total Nitrogen
Major Inorganic Ions	Water-rock chemistry and NPS influence	Cl^-, F^-, SO_4^-
Metals	Water-rock chemistry	Al, As, Ba, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Zn
Organics	NPS influence	Pesticides: Alachlor, Atrazine, Cyanazine, Glyphosate, Metalochlor, Simazine
Volatile Organic Compounds	NPS and point source influences	Benzene, Ethylbenzene, Toluene, Xylenes, Methyl-tert-butyl ether (MTBE)

Basic descriptive statistics were performed on all analyte groups, giving the number of samples, percent of non-detections, quartiles and standard deviation. Trends were determined by calculating the Kendall's tau-b for each station. While significance of a trend was not determined for each station, a determination of a monotonic trend for stations within subgroups (physiographic region, wells, springs, or all sites) was determined. Trends were calculated for all analytes within analyte groups with the exception of pesticides and VOCs. The high proportion of non-detections for pesticides and VOCs made tests for trends impossible.

Trends were found within each analyte group. Additionally, trends for analytes varied for each physiographic region evaluated. In general, increasing trends were more frequent in the Mississippian Plateau physiographic region and in stations that are springs, as opposed to wells. An obvious contributor to this result is the power found in detecting trends with a larger number of samples or stations. Of the six physiographic regions, the Mississippian Plateau has 24 of the 49 stations. The sample size difference between wells and springs is large, but not as marked – 20 wells versus 29 springs. Adding monitoring stations in the under-represented physiographic regions as well as more wells to the Network would be needed to resolve this issue.

While baseline data have been gathered and groundwater resources have been characterized, continued and expanded monitoring will further our understanding of groundwater quality in Kentucky. The finding of trends points to ongoing changes in this resource, with implications regarding land-use activities, protection and conservation efforts, and public health and economic development. With continued vigilance, stresses on this resource can be addressed and rectified before negative outcomes are realized.

IMPROVING KARST/SINKHOLE HAZARD ASSESSMENT IN KENTUCKY

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Karst and sinkholes are well recognized as geologic hazards in Kentucky and were included for risk assessment in the 2013 State Hazard Mitigation Plan. In the 2013 plan, karst/sinkhole hazard was assessed statewide using a formula that sums the percentage of areas with potential for karst development and the percentage of areas of sinkhole occurrence to calculate karst/sinkhole hazard scores. Because areas identified as having the potential for karst (mapped outcrops of carbonate bedrock at or near land surface) are much larger than areas of mapped sinkhole occurrences (which are closed depressions identified on 1:24,000-scale topographic maps), the spatial distribution of the karst/sinkhole hazard scores is mostly dominated by karst potential information and is little influenced by sinkhole occurrences. However, sinkhole occurrence is a proxy measurement of karstification, which is also influenced by additional important hydrogeologic factors including soil thickness, bedrock porosity and permeability, topography, and surface and subsurface drainage. Because the formation of sinkholes is generally recognized as the most prominent karst-related hazard in Kentucky, we believe the method used to assess karst/sinkhole hazard should give more weight to the information on sinkhole occurrences.

To better incorporate information about sinkhole occurrences, we tested two modifications to the 2013 karst/sinkhole hazard assessment method. The first modification assigns a higher weight to areas of sinkhole occurrence than to areas with karst potential. The second modification substitutes sinkhole density (number of sinkholes per square kilometer) for percentage area of sinkhole occurrences, and equally weights sinkhole density and karst potential area.

For the first method, we found that it is difficult to adjust sinkhole-occurrence weights in a way that meaningfully improves upon the 2013 hazard scores. The spatial distribution of karst/sinkhole hazard scores calculated from the second method better reflects sinkhole occurrences while also considering information on karst potential areas. Using the second method, the karst/sinkhole hazard scores can potentially be further improved as more accurate sinkhole density can be obtained when high-resolution topography maps derived from LiDAR become available statewide.

COMBINATION OF WIND AND STACK EFFECTS ON INDOOR, ATMOSPHERIC, AND SUBSURFACE DOMAINS IN VAPOR INTRUSION STUDIES

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Vapor intrusion (VI) is a process in which volatile organic compounds (VOCs) volatilize from contaminated groundwater or soil and transport through the subsurface into overlying buildings. Indoor air contamination caused by VI is difficult to characterize because indoor air concentrations varies temporally and spatially in homes throughout impacted communities. Different sources have been known for this variability, two of them are the building air exchange rate (AER) and pressure difference between indoor and outdoor (ΔP). AER and ΔP in a building are influenced by different parameters such as wind and stack (temperature) effect, building characteristics, mechanical ventilation and occupant behavior (Figure 1). To date, a few VI models have been developed to evaluate the effect of wind flow and indoor air temperature on VI. Most of the wind-focused VI models have investigated how wind flows influence subsurface processes. There is a need to modify existing models to understand how wind flow and temperature collectively influence the VI exposure risks.

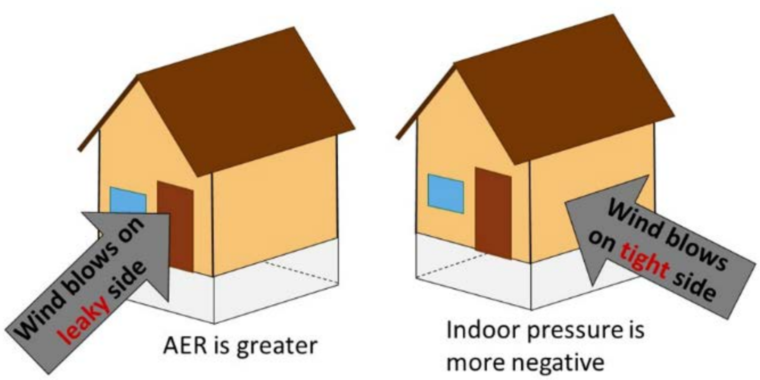

Figure 1: Wind direction effect on AER and ΔP
Source: Shirazi and Pennell (2017), Environmental Science: Processes & Impacts

In this study, we present results of a newly developed model that combines three different domains: the atmospheric domain (outdoor above-ground), indoor domain, and subsurface (groundwater contamination) domain. Using this new model, we investigate how wind flow above and around a building, as well as stack effects influences 1) the distribution of VOCs in the subsurface, and 2) indoor air pressure which consequently affects the indoor air concentration of contaminant.

The results of this research indicate that wind and stack effect influence both air exchange rate of the building and indoor pressure (Figure 2). As shown below, when wind speed increases, the building AER value increases. In addition, wind direction can influence AER, especially for a 10 m/s wind speed (Figure 2a). For a constant wind speed, AER reaches the highest value when wind blows on the leakier (north and south) sides of the building and lowest values when wind blows on the tighter (east and west) sides of the building. Figure 2b shows that wind speed and direction influence the basement pressure which consequently influence the driving force for soil gas to enter the building and cause in VI exposure risks.

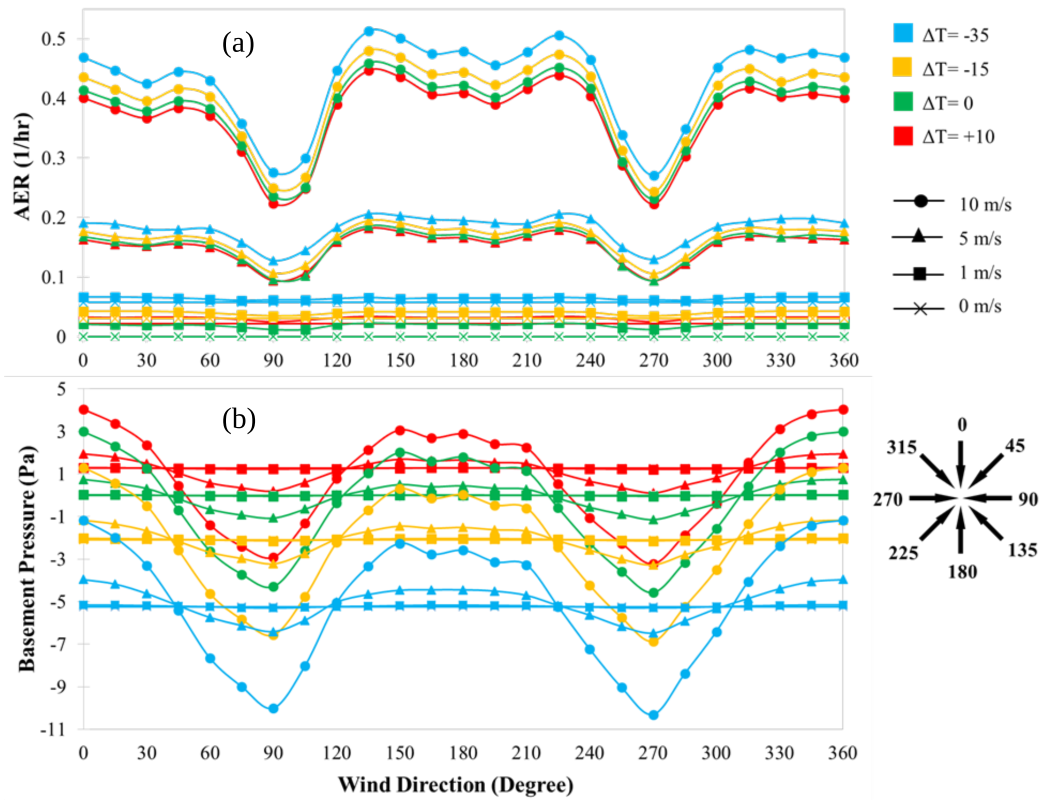

Figure 2: Wind and Stack Effect on Building AER (a) and Basement Pressure (b)

The mass entry rate of the contaminant through the foundation crack is inversely related to the basement pressure. The building AER is a dominant factor that controls the indoor air concentration in the first floor, however AER is not the dominant factor in the basement since the basement is tighter that first floor. These results highlight that building characteristics play an important role in changing indoor air concentration in different zones of buildings. More results and implications are included in a recently published paper in *Environmental Science: Processes & Impacts* (DOI: 10.1039/c7em00423k 19:1594-1607).

Acknowledgements: The project described was supported by a CAREER Award from the National Science Foundation (Grant Number 1452800) and by Grant Number P42ES007380 (University of Kentucky Superfund Research Program) from the National Institute of Environmental Health Sciences.

CHARACTERIZATION OF SPRING DISCHARGE AND KARST/SINKHOLE DRAINAGE FEATURES AT THE HOMEPLACE ON GREEN RIVER, NEAR CAMPBELLSVILLE

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Rolling topography shaped by sinkholes dominates much of the agricultural landscape in Kentucky's karst areas. Each sinkhole is an isolated topographic basin that captures surface runoff and drains it underground to subsurface karst conduits and eventually to karst springs and surface streams. Identification and mapping of sinkholes, subsurface karst flow routes, and springs receiving sinkhole drainage from farmland are needed to effectively monitor potential agricultural contaminants. Quantifying a receiving spring's discharge is necessary for estimation of agricultural contaminant loads, and characterizing the spring's response to rainfall-runoff is beneficial to the collection and interpretation of water-quality sampling data. These objectives are the focus of a current investigation being conducted by KGS in collaboration with the U.S. Department of Agriculture Natural Resources Conservation Service at The Homeplace on Green River, a historic farm near Campbellsville managed by a 501c3 organization promoting agricultural conservation and education.

A continuous-discharge monitoring station was established in June 2017 at a perennial spring that discharges from a small cave at The Homeplace. Water from the spring flows in a shallow channel consisting of alternating pools and riffles mostly filled with coarse, cherty gravel. Shallow water depth, the gravel bed load, and channel-bank instability make repeated accurate measurement of the spring's discharge a difficult task. To overcome these obstacles, we installed an aluminum flume, stilling well, pressure transducer, and data-logger/telemetry equipment. The flume creates a stable, artificial channel reach and enables accurate discharge measurements by constricting the width of flow and increasing flow velocities and water depths within it. Discharge is calculated using a mathematical equation that relates the depth of water measured at a single point in the flume to the volume of water flowing through the flume per unit of time. Water level (depth) changes in the flume are measured at 15-minute increments by the pressure transducer in the nearby stilling well, which is isolated from groundwater or surface water inflow but hydraulically connected to the flume. The water-level data are automatically transmitted four times a day by the telemetry system. Base-flow discharge of the spring appears to be a relatively steady 68 gpm (0.15 cfs); however, the spring's flashy response to precipitation ranges into the hundreds of gallons per minute. For example, rainfall associated with Tropical Storm Cindy on June 22–24 resulted in spring discharge that exceeded 550 gpm (1.23 cfs) at the peak of the storm pulse. The flume was washed out by an intense thunderstorm during November 2017, but will be reinstalled early in 2018. A multiparameter water-quality logger will also be installed at that time to begin monitoring changes in spring water pH, temperature, conductivity, and turbidity.

To delineate surficial drainage features on the farm and in the adjacent 22 mi^2 study area, we used processed LiDAR topographic data to identify probable sinkhole depressions and delineate topographic drainage divides between sinkholes and for watersheds of area streams. The LiDAR data were also used to estimate the maximum depths of each sinkhole depression and identify probable locations of swallets (open sinkhole throats). LiDAR-indicated sinkholes were field verified with the assistance of the ArcGIS field mapping app Collector. This application allowed georeferenced notes and photos to be recorded that document the physically observable characteristics of individual sinkholes. In addition, in March-April 2017, we conducted electrical-resistivity surveys at five selected sinkhole locations on the farm. Anomalies indicating karst conduits at shallow depths and trending in the direction of the spring were identified on most ER survey profiles. No dye-tracer tests have been attempted as of yet to identify which sinkholes contribute drainage to The Homeplace farm spring, but this work is planned to begin in the spring of 2018.